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LATERAL SPREAD OF SONIC BOOM MEASUREMENTS FROM US AIR FORCE BOOMFILE FLIGHT TESTS

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13. ABSTRACT *(Maximum 200 words)*
A series of sonic boom flight tests were conducted by the US Air Force at Edwards AFB in 1987 with current supersonic DoD aircraft. These tests involved 43 flights by various aircraft at different Mach number and altitude combinations. This paper compares the measured peak overpressures to predicted values as a function of lateral distance. Some of the flights are combined into five groups because of the varying profiles and the limited number of sonic booms obtained during this study. The peak overpressures and the lateral distances are normalized with respect to the Carlson method predicted centerline overpressures and lateral cutoff distances, respectively, to facilitate comparisons between sonic boom data from similar flight profiles. This paper demonstrates that the data obtained in this study agrees with sonic boom theory and previous studies and adds to the existing sonic boom database by including sonic boom signatures, tracking, and weather data in a digital format.

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PREFACE

This report analyzes the measured sonic boom data in the BOOMFILE database with predicted data. This study was conducted under Task 723134, "Exploratory Noise and Sonic Boom Research." The author wishes to gratefully acknowledge Ms Jackie Brennaman and Ms Bea Heflin for the preparation of this report and to Mr Jerry Speakman, Dr Ken Plotkin, and Dr Domenic Maglieri for their technical and editorial comments.

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INTRODUCTION

In 1987, the Armstrong Laboratory of the US Air Force conducted a sonic boom measurement study at Edwards Air Force Base. This study had three basic goals. The first goal was to collect reference sonic boom signatures for the current inventory of DOD supersonic aircraft. The second goal was to perform the first complete field test of the newly developed unmanned Boom Event Analyzer Recorder (BEAR)[1,2], which records the full sonic boom waveform in a digital format. The third goal was to measure the lateral spread of the sonic boom carpet and capture full sonic boom signatures near lateral cutoff. This paper involves the third aspect of this study by comparing the lateral spread of the sonic booms to predicted values. Several previous studies have measured the lateral spread of sonic booms [3-10]. This study enhances the results of the earlier studies by including weather and tracking data along with full sonic boom waveforms. All of these data are stored in a digital format and are available upon request from the Noise Effects Branch of the Armstrong Laboratory (AL/OEBN Area B Bldg 441, Wright-Patterson AFB, Ohio 45433, (513)255-3664).

TEST DESCRIPTION

The tests consisted of near steady supersonic flights at various Mach number and altitude combinations by various aircraft[11]. Table 1 lists the flights performed during this study along with the aircraft and the nominal flight conditions (i.e. Mach number and altitude). The sonic booms were measured by a monitor array which consisted of 13 BEAR units and 9 modified dosimeters. Figure 1 displays the layout of the test area along with the target ground track and monitor locations. The lateral portion of the array was 24 miles in length. The target intersection between the flight tracks and the array separated the array into two sections. One section extended 6 miles north of the targeted flight track, and the other section extended 18 miles south. The actual flight track intersections with the array, which are provided in Table 1, were scattered along the array by up to 4 miles from the targeted intersection. The actual Mach number and altitude profiles were also scattered about the targeted conditions. Weather and tracking data were obtained during the study. The weather data include three daily rawinsonde launches and ground station observations which obtained temperature, pressure, dew point,

Table 1. BOOMFILE Flight Conditions Summary

DATE	AIRCRAFT	FLIGHT TRACK INTERSECTION	MACH NUMBER	ALTITUDE (Ft MSL)	BOOM AT SITE 00 (Local Time)	FLIGHT # AND GROUP
31 JUL 87	F-4	57.8	1.20	16000	08:41:20	1 C
03 AUG 87	F-4	60.1	1.24	29200	07:48:33	2 B
	F-4	60.6	1.29	29300	07:58:33	3 B
	F-4	53.6	1.10	13000	08:08:04	4
	F-4	59.2	1.10	14400	10:29:59	5 D
	F-4	61.3	1.37	44400	10:43:22	6 A
	T-38	58.6	1.00	13600	10:05:35	7
	T-38	56.0	1.10	13000	10:12:15	8
	T-38	59.5	1.11	29600	12:28:18	9
	T-38	60.5	1.05	21200	12:38:17	10
04 AUG 87	AT-38	60.0	1.17	41400	07:19:41	11
	AT-38	60.0	1.12	32300	07:30:09	12
	AT-38	63.0	1.15	16700	07:36:46	13
	AT-38	59.6	1.20	30300	09:14:06	14
	AT-38	59.0	1.10	14000	09:23:15	15
	F-15	61.5	1.38	41400	07:56:42	16
	F-15	60.3	1.20	29700	08:04:06	17
	F-15	60.6	1.10	12500	08:10:13	18 D
	F-15	60.0	1.13	15200	10:46:15	19 D
	F-15	59.0	1.28	31000	10:02:18	20 B
	F-15	64.0	1.42	45000	11:11:28	21 A
	F-15	60.0	1.40	45500	11:34:21	22 A
05 AUG 87	F-16	57.0	1.25	29500	09:06:05	23 B
	F-16	60.0	1.43	46700	09:33:54	24 A
	F-16	58.8	1.17	19300	09:44:51	25
	F-16	59.5	1.13	14400	11:44:24	26 D
	F-16	60.6	1.12	13800	11:54:39	27 D
	F-16	60.5	1.25	30000	12:04:46	28 B
	SR-71	60.8	2.50	64800	09:26:12	29 E
	SR-71	59.8	3.00	73000	10:55:12	30 E
	SR-71	59.4	1.23	32400	11:08:38	31
	SR-71	62.0	1.70	52000	12:35:51	32 E
06 AUG 87	F-18	60.0	1.30	30000	07:44:12	33 B
	F-18	59.6	1.40	44700	0757:05	34 A
	F-18	58.0	1.10	14200	08:10:36	35 D
	F-18	59.8	1.30	30000	10:22:47	36 B
	F-18	59.8	1.43	45000	10:34:14	37 A
	F-18	59.8	1.10	13000	10:48:38	38 D
	F-14	56.2	1.20	31500	08:28:45	39
	F-14	62.0	1.27	16500	10:43:43	40 C
	F-111F	59.8	1.20	14000	11:48:18	41 C
	F-111F	59.8	1.40	45000	12:04:44	42 A
07 AUG 87	F-111	58.3	1.25	29900	10:50:26	43 B

relative humidity, and wind data. Tracking data, obtained for all but three flights, include ground position, altitude, Mach number, climb angle, and heading angle. These supporting data help to identify the actual conditions under which the sonic booms were generated, propagated, and measured.

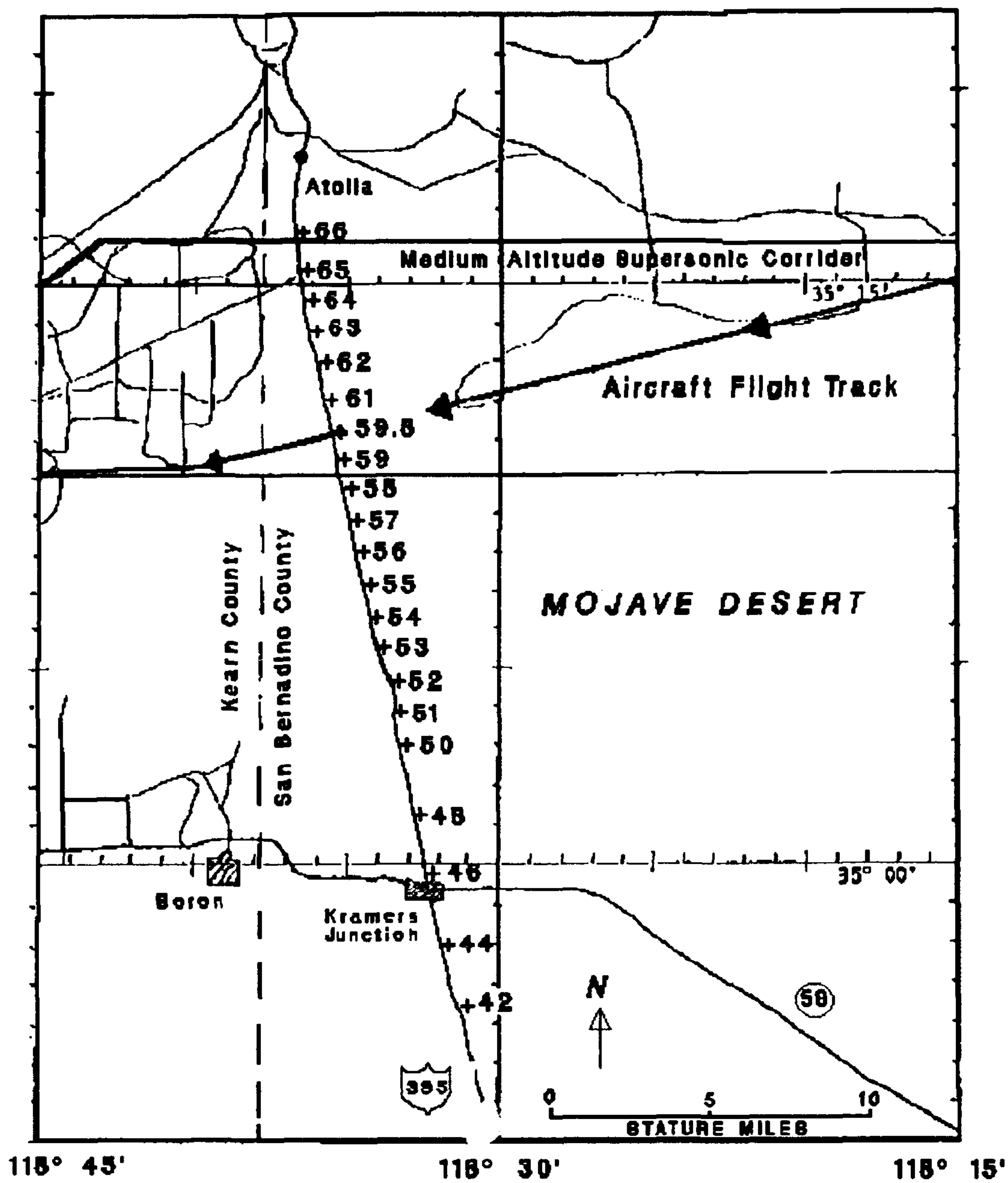

Figure 1. Layout of test area with the target ground track and monitor array

COMPARISON OF THE PEAK OVERPRESSURES

Comparisons of the measured overpressures to Carlson predictions[12] are done in two ways to relate this new database to previous efforts. First, the overall peak overpressures obtained from the BEAR units are compared to predictions. Second, the data is divided into five selected groupings of the flights to facilitate a better comparison of the lateral spread of the measured data to the predicted values.

Overall Comparison of the Peak Overpressures

As in previous studies[5,7,8,10], the ratio of measured peak overpressures to predicted is used to derive a probability curve for the data. This curve demonstrates the expected normal variation of sonic boom overpressures due to atmospheric effects which can cause rounded and peaked N-wave signatures[13-15]. This curve estimates the probability that a given sonic boom overpressure will exceed a certain value. The calculated values were evaluated by Carlson's method with a 1972 U.S. Standard Model Atmosphere. This ratio allows the various peak overpressures to be combined without any restriction to aircraft shape, Mach number, and altitude. The peak overpressure data is divided into two groups by their lateral propagation distance. The selected division point is 50% of the calculated lateral cutoff point, *dyc*. In this database there are 278 valid data points in the < 50% of *dyc* group and 91 valid points in the > 50% of *dyc* group. This grouping excludes 24 points where no measured values were obtained and 70 points where signatures were measured beyond the predicted lateral cutoff. Some of these signatures obtained beyond *dyc* are reduced overpressure N-waves, while others may be classified as rumble waves. Figure 2 shows the probability curves for the two groups along with their histograms in terms of the measured to predicted ratio. The two probability curves and histograms agree with those given for previous sonic boom measurement studies[5,7,8,10]. The curve for data points < 50% of *dyc* lies in a straight line in the region about a ratio of 1.0 and flattens as the two extremes are reached. The 50% probability point corresponds to a ratio of 0.83 which means the predictions are, in general, overestimating the peak overpressures. The curve for the > 50% of *dyc* group is shifted to the left and tends to flatten sooner. This shift indicates that the calculated values are overestimating the actual measurements to a greater extent in this region. In both curves the flattened portion may be attributed to the limited number of data points used to derive the curves. This simple analysis demonstrates

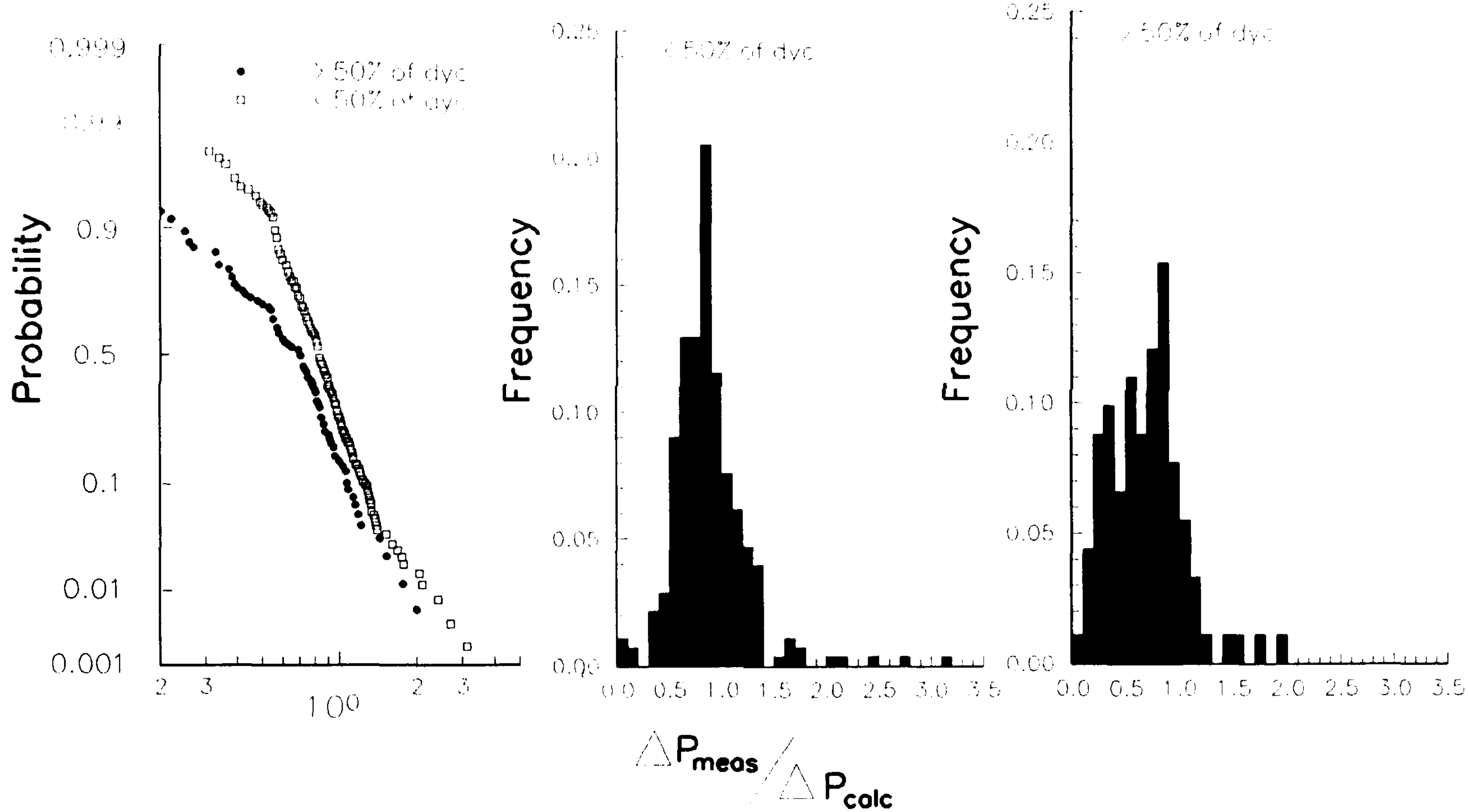

Figure 2. Probability curves and histograms for the ratio of measured to predicted peak overpressures in the BOOMFILE database

that this sonic boom database agrees well with past sonic boom measurements, even though this database is much smaller. In addition, this database confirms the trend that theory tends to overpredict the overpressure as the lateral distance approaches the predicted cutoff point[5,8].

Comparison of Peak Overpressure vs Lateral Distance

The following analysis is meant to highlight some of the data contained within the BOOMFILE database. This comparison will examine more closely the lateral spread of the sonic boom overpressures. Some of the flights are combined into groups to collapse the limited data. Twenty-eight of the flights are separated into five groups according to their nominal flight conditions in the following Mach number-altitude combinations: A) 1.4 M at 45 kFt, B) 1.25 M at 30 kFt, C) 1.18 M at 16 kFt, D) 1.1 M at 14 kFt, and E) SR-71 at Mach numbers greater than 1.5. This grouping of flights are also noted in Table 1. The peak overpressure data, measured and predicted, are combined by normalizing the overpressure and the lateral propagation distance. The peak overpressures are normalized by the predicted centerline overpressure, and the lateral distances are normalized with respect to the predicted lateral cutoff. The predictions use the actual flight conditions as listed in Table 1. This procedure allows the limited data from this study to be combined for better comparison of the lateral spread of the boom carpet and analysis between the various flights performed during this test. From the probability curves, measured values should be overestimated as the lateral distance approaches *dyc*.

Comparison of Group A Overpressures

Figure 3 displays the peak overpressures as a function of lateral distance for Group A flights, whose nominal flight conditions are around 1.4 M at 45 kFt MSL. For points < 50% of *dyc*, the measured overpressures are scattered about the predicted value, but for points > 50% of *dyc*, the measured values fall below predictions as expected from the probability analysis shown in Figure 2. In Figure 3 an amplified peak overpressure is highlighted with a normalized overpressure of 2.4 at the centerline of the boom carpet. This boom was generated by an F-4 operating at 1.37 M at 44.4 kFt MSL (flight #6). Figures 4 shows this sonic boom signature. The signature is not a normal N wave but seems to be a combination NU wave with an increased peak overpressure of over two times the normal N wave peak

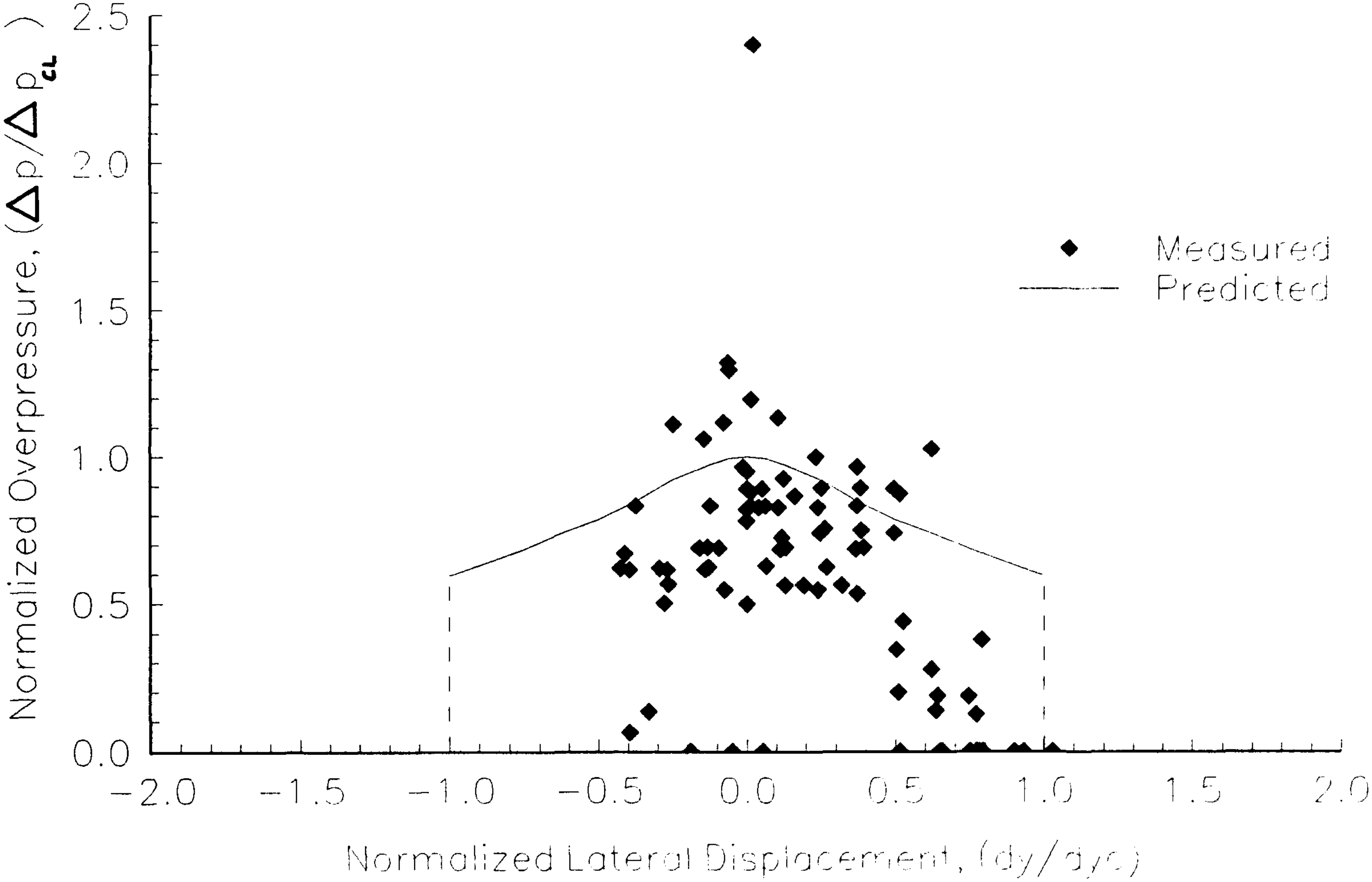

Figure 3. Normalized peak overpressures as a function of the normalized lateral propagation distance for flight with nominal conditions of 1.4 M at 45 kFt MSL

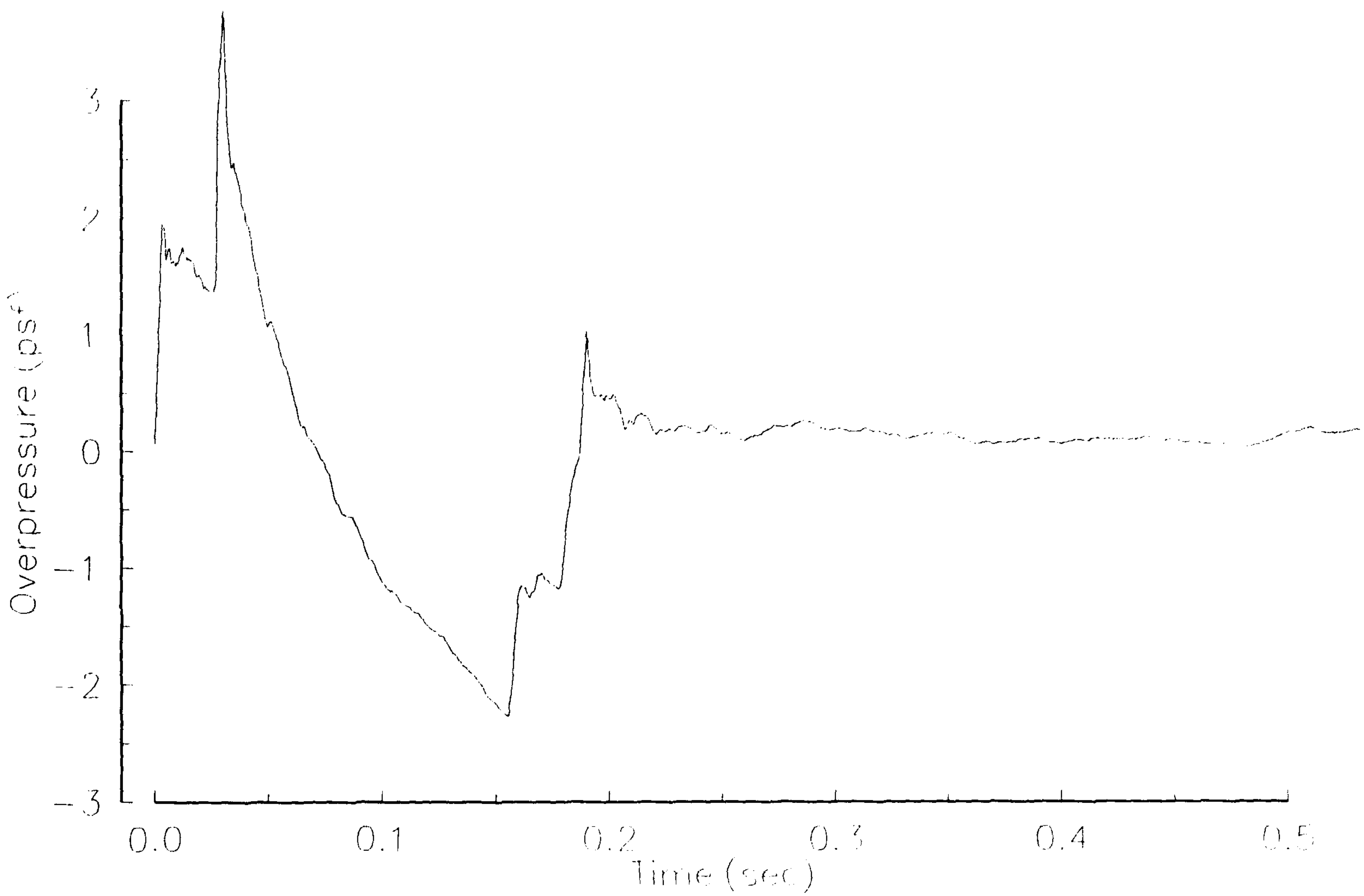

Figure 4. Peaked sonic boom signature generated by an F-4 at 1.37 M at 44.4 kFt MSL (flight #6) measured under the flight track

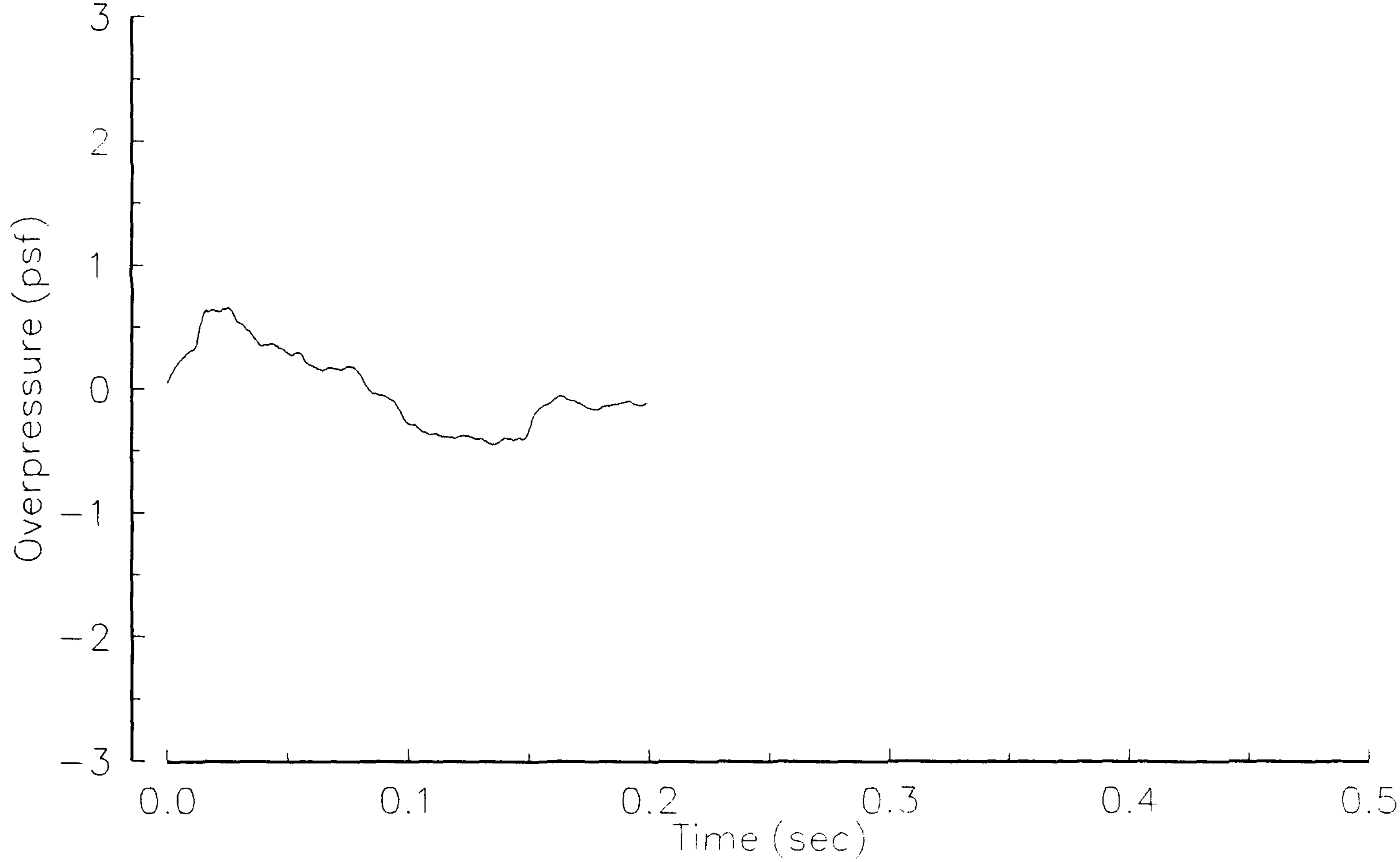

Figure 5. Rounded sonic boom signature generated by an F-15 at 1.4 M at 45.5 kFt MSL (flight #22) measured 12 lateral miles from the flight track

overpressure. Also, note that the initial shock overpressure of 2 psf from this signature falls within the expected variation about the predicted value of 1.5 psf. Figure 3 also shows a number of points > 50% of *dyc* where the measured overpressures are much smaller than the predicted value. Figure 5 presents one of these reduced overpressure signatures. This sonic boom signature was generated by an F-15 flying at 1.4 M at 45.5 kFt MSL (flight #22) and measured at a lateral distance of 80% of predicted *dyc*. This signature retains a basic N-wave shape, but its peak overpressure is much lower than the calculated value. The other signatures in this same region have both normal and rounded N-wave characteristics.

Comparison of Group B Overpressures

The lateral spread of the peak overpressures for flights in Group B with 1.25 M at 30 kFt MSL nominal flight conditions is shown in Figure 6. This figure also demonstrates that near the centerline the overpressures are scattered about the predicted values as expected, but as the lateral distance approaches the cutoff point, the measured overpressures tend to be less than predicted. In this figure, some measured signatures were obtained just beyond *dyc*, but within an expected variation of *dyc*, and the overpressure are less than the predicted value at cutoff. Figure 7 displays one of these signatures which was generated by an F-15 flying at 1.28 M at 31 kFt MSL (flight #20). This signature was obtained at a 11 mile lateral distance which was only 6% longer than the predicted *dyc*. This signature has retained its N-wave shape although it was obtained near the lateral cutoff region. An amplified overpressure of 2.3 is also noted in Figure 6. This amplified boom was generated by an F-18 flying at 1.3 M at 30 kFt MSL (flight #33) and is plotted in Figure 8. This signature contains a double boom signature which has a normal N wave followed by an NU combination wave with an increase in the peak overpressure. The peak overpressure of the first boom agrees with the calculated value, and the second boom appears to be caused by some unsteady aspect of the flight profile. Tracking for this event is provided in Figure 9 and shows that the aircraft had a slight turn as it approached the array which could be the cause of the second, focused boom. This signature was obtained at a lateral offset of 4 miles which was at 40% of the predicted lateral cutoff, yet other measurement sites beyond this point only obtained rumbled signatures even though they were within the predicted *dyc*. This signature

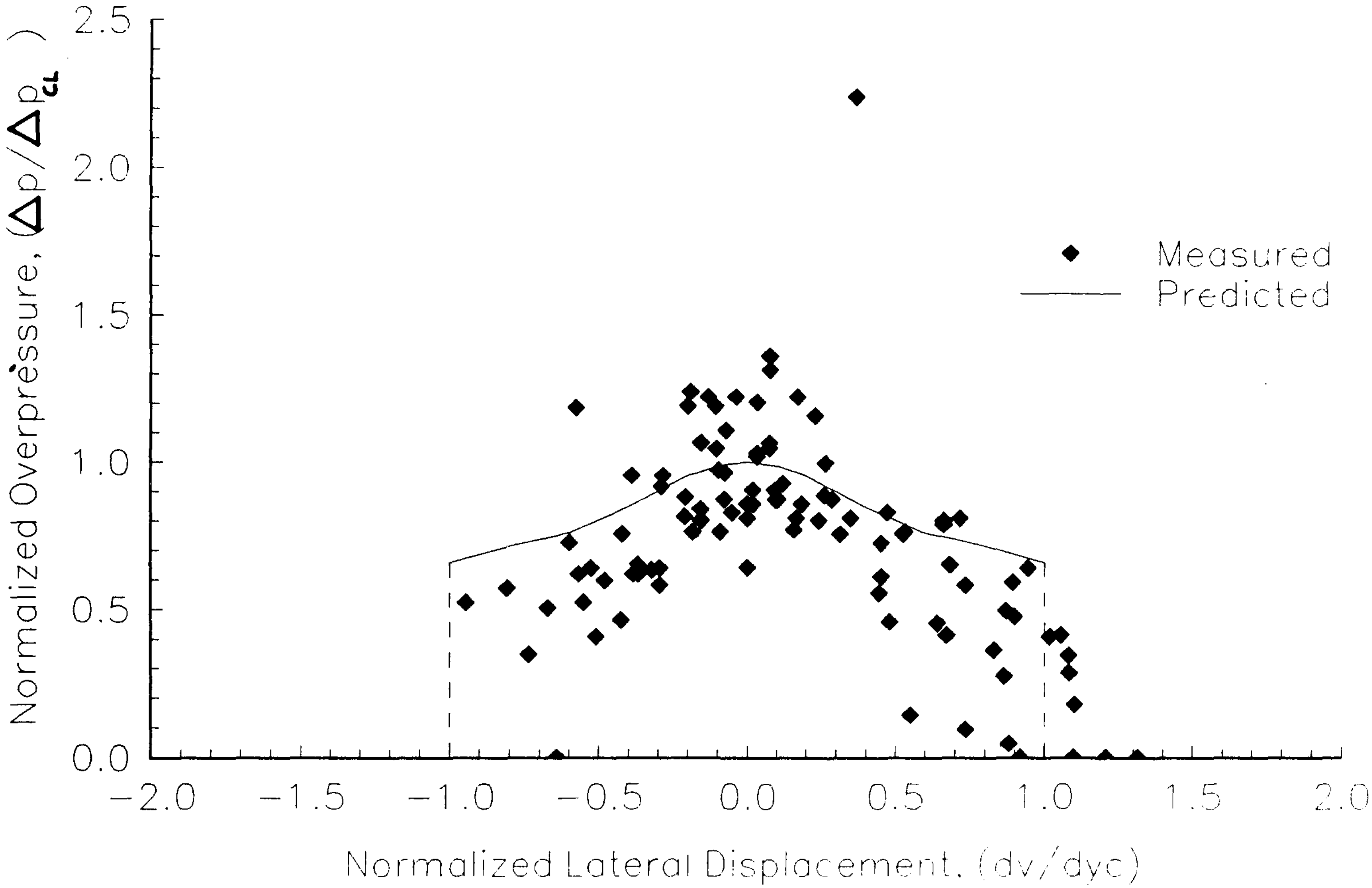

Figure 6. Normalized peak overpressures as a function of the normalized lateral propagation distance for flight with nominal conditions of 1.25 M at 30 kFt MSL

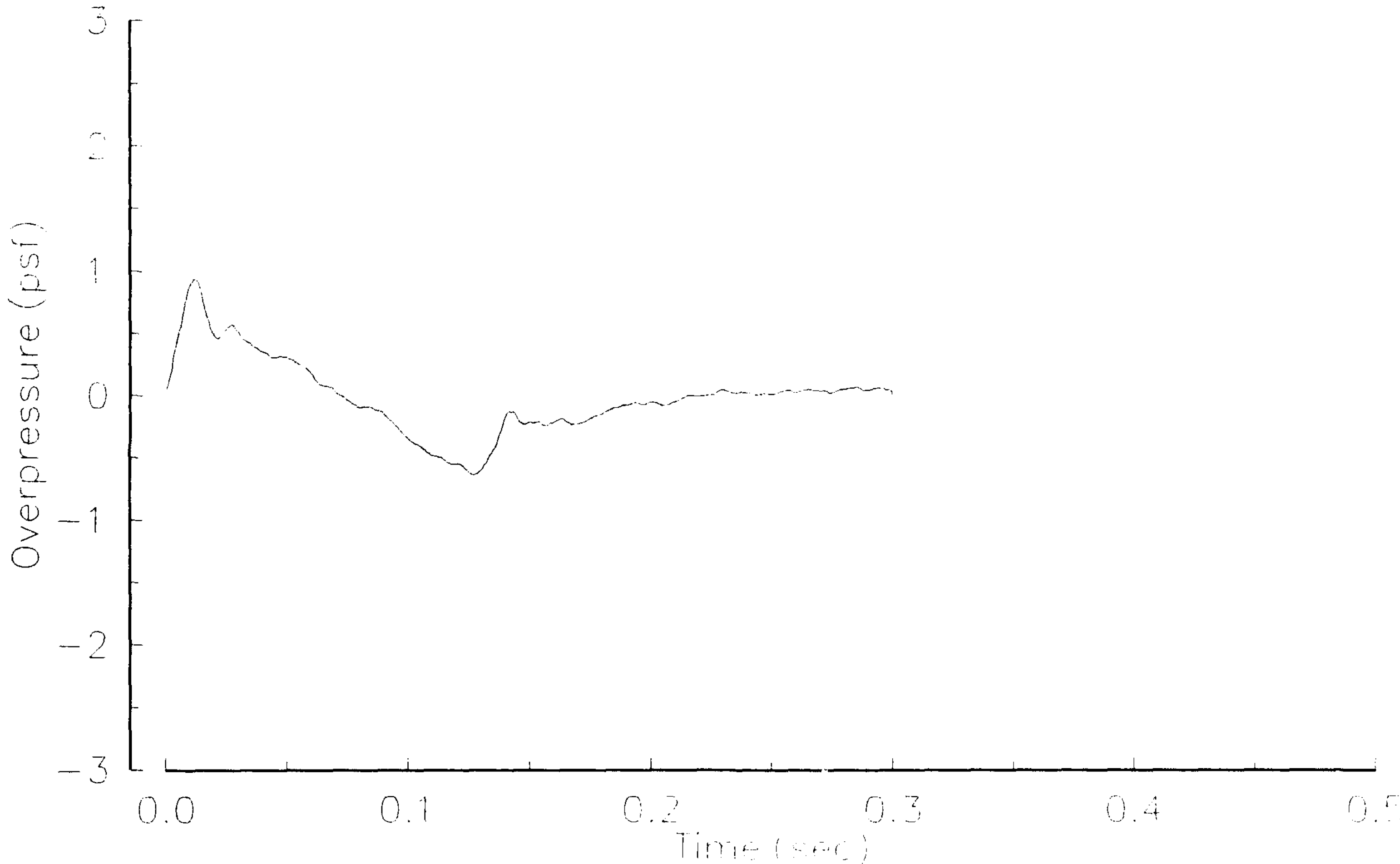

Figure 7. Sonic boom signature near lateral cutoff generated by an F-15 at 1.28 M at 31 kFt MSL (flight #20) measured 11 lateral miles from the flight track

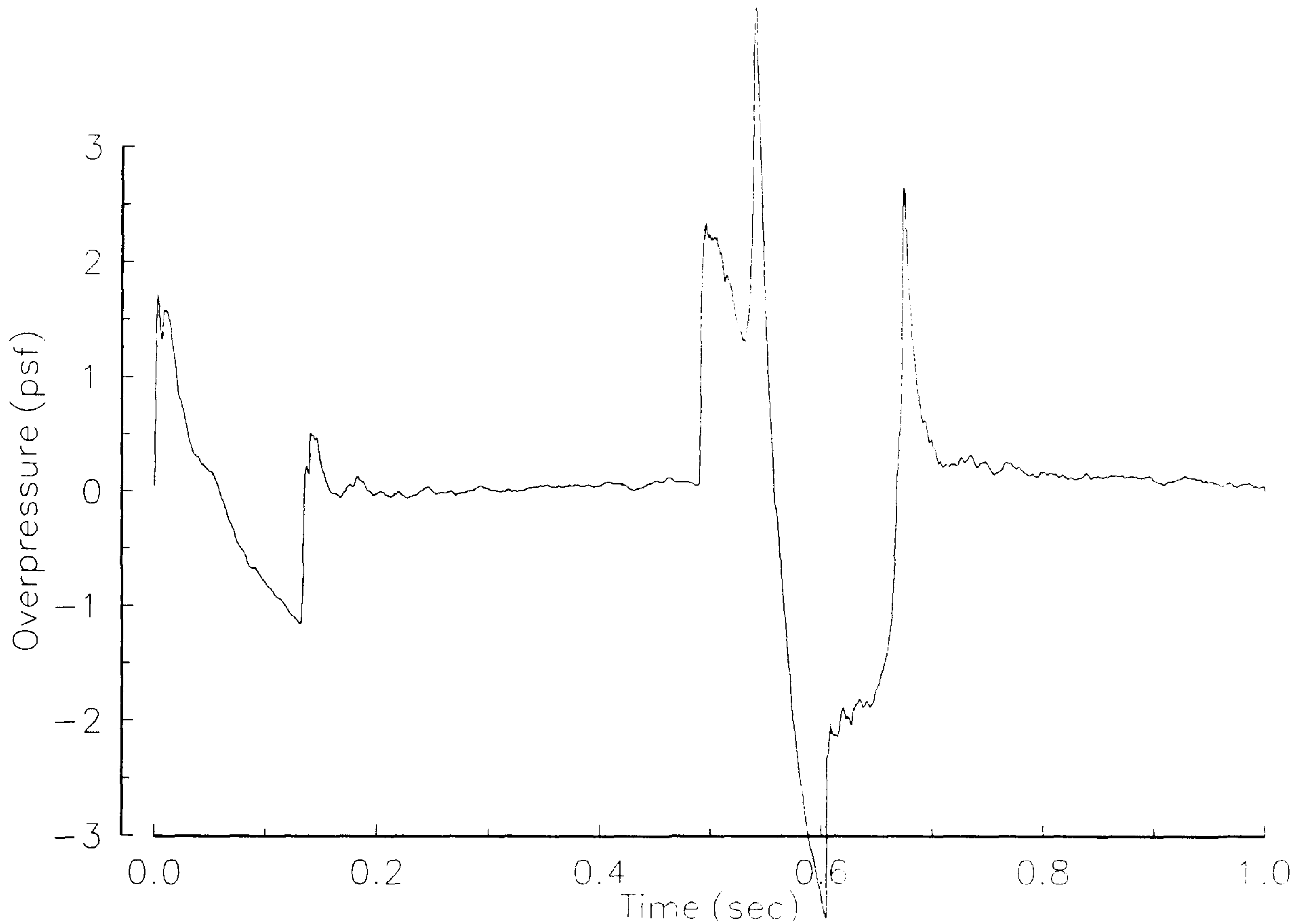

Figure 8. Double sonic boom signature generated by an F-18 at 1.3 M at 30 kFt MSL (flight #33) measured 4 lateral miles from the flight track

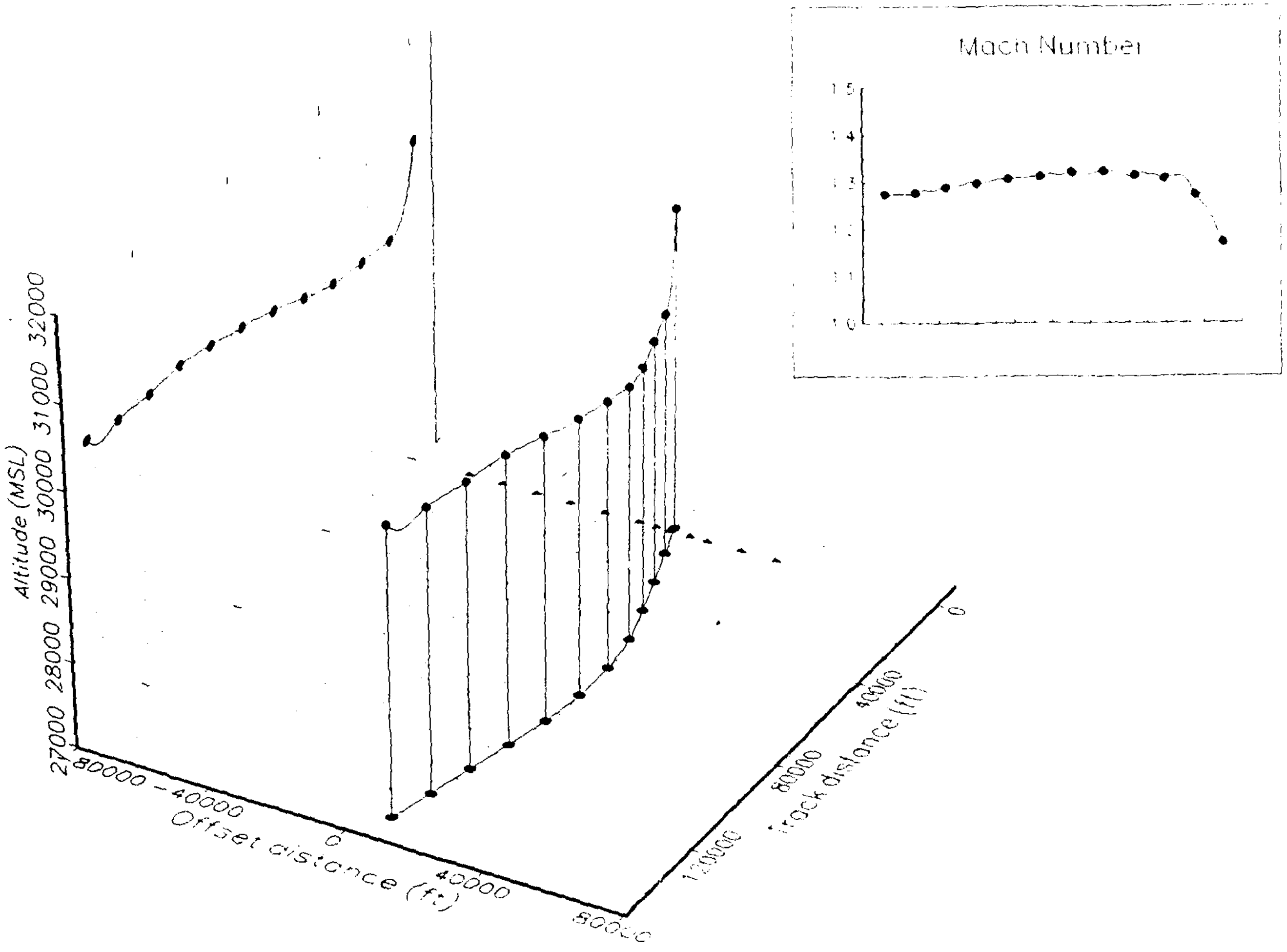

Figure 9. Tracking plot of F-18 flight #33

highlights some of the non-normal sonic boom signatures, which need a more thorough analysis to explain and quantify their shapes, that were obtained during this study.

Comparison of Groups C & D Overpressure

For Group C with nominal flight conditions at 1.18 M at 16 kFt MSL, Figure 10 displays the same trend of reduced measurements compared to calculated values as the lateral distances increases, as seen in Figures 3 and 6. This figure also shows that some signatures were collected at points up to 1.8 times the predicted *dyc*. These signatures beyond *dyc* are rounded signatures like the one demonstrated in Figure 11. This rumbled signature was produced by an F-111 at 1.2 M at 14 kFt MSL (flight #41) and measured at a lateral distance of 9.8 miles (1.5 *dyc*). This type of rumbled signature is expected for such long propagation distances beyond *dyc*. For Group D flights, which have nominal flight conditions at 1.1 M and 14 kFt MSL, more signatures were obtained beyond *dyc*, as shown in Figure 12. The expected lateral cutoff point for this group is about 4 miles. Most of these signatures are well rounded and barely retained any N-wave characteristics. For these lower and slower flights, the carpet widths are more sensitive to variations in the atmosphere, flight track, and the Mach number. Even with the measured signatures beyond *dyc*, the trend of overestimating the peak overpressures at the more laterally displaced locations is still present. A more comprehensive analysis on these two groups of flights should lower the uncertainty in predicting lateral cutoff and provide answers to the seemingly long lateral propagation distances evidenced in Figure 12.

Comparison of SR-71 Overpressures

Another comparison is shown for the SR-71 flights which were above 1.5 M. Figure 13 shows that the peak overpressures were consistently overpredicted in this analysis except for one event which is given in Figure 14. This signature was generated at 1.7 M at 52 kFt MSL (flight #32) and exhibits a pronounced peak in the signature. This peak is caused by variations in the atmosphere since there are corresponding peaks at each shock in the signature. This signature is an example of the peaked signatures that are contained in this database.

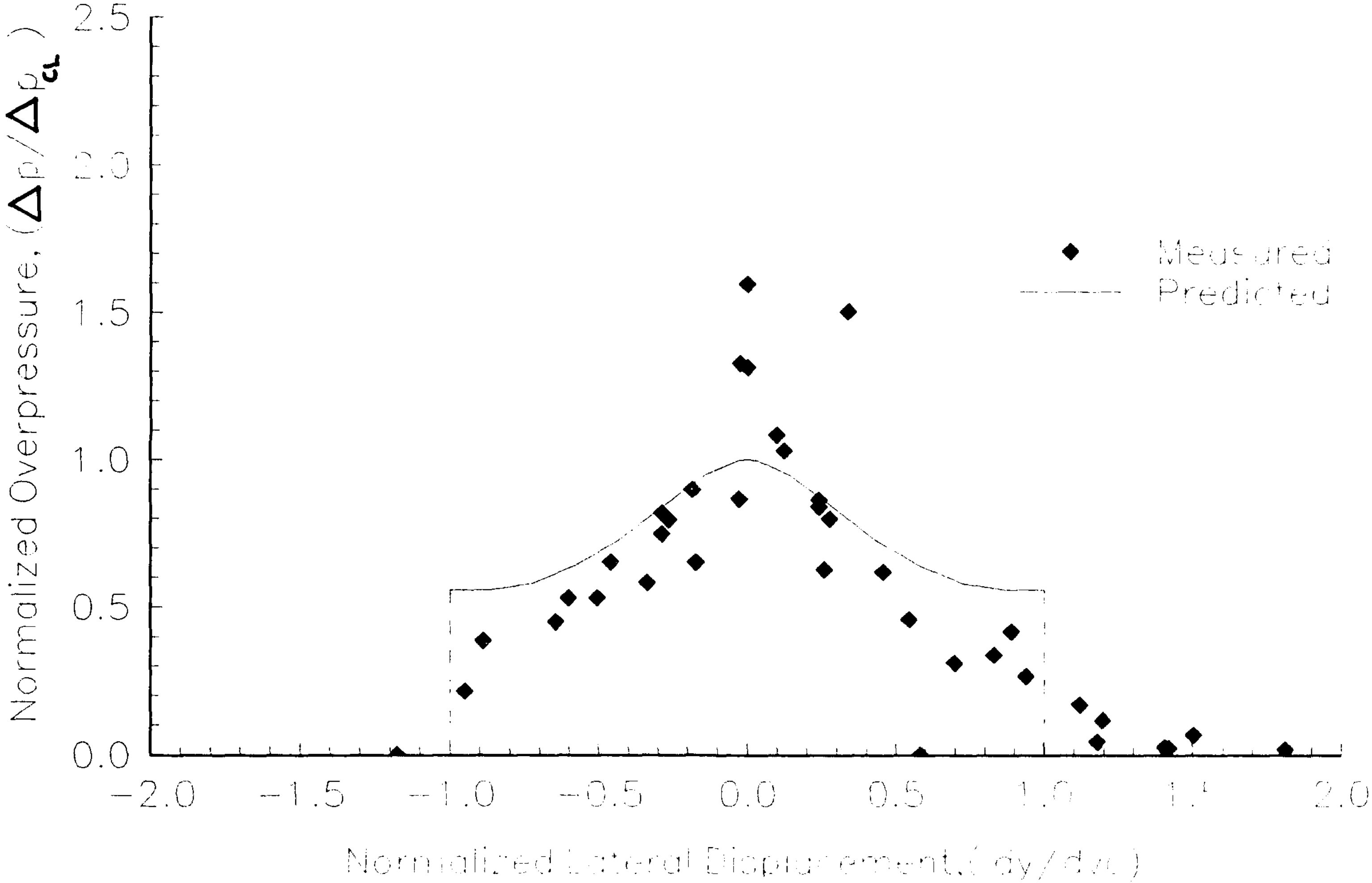

Figure 10. Normalized peak overpressures as a function of the normalized lateral propagation distance for flight with nominal conditions of 1.18 M at 16 kFt MSL

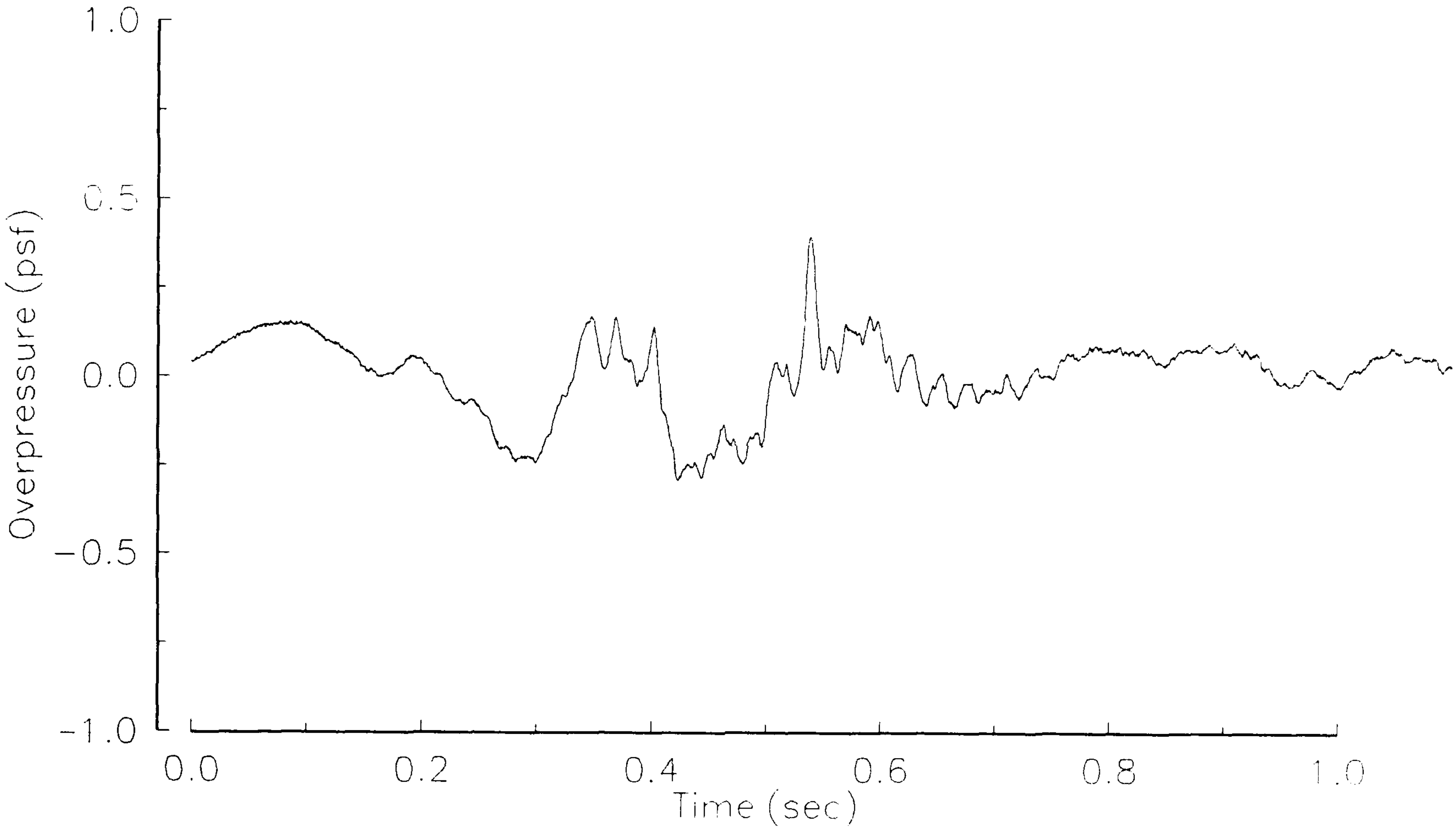

Figure 11. Rumble pressure signature generated by an F-111 at 1.2 M at 14 kFt MSL (flight #41) measured 10 lateral miles from the flight track

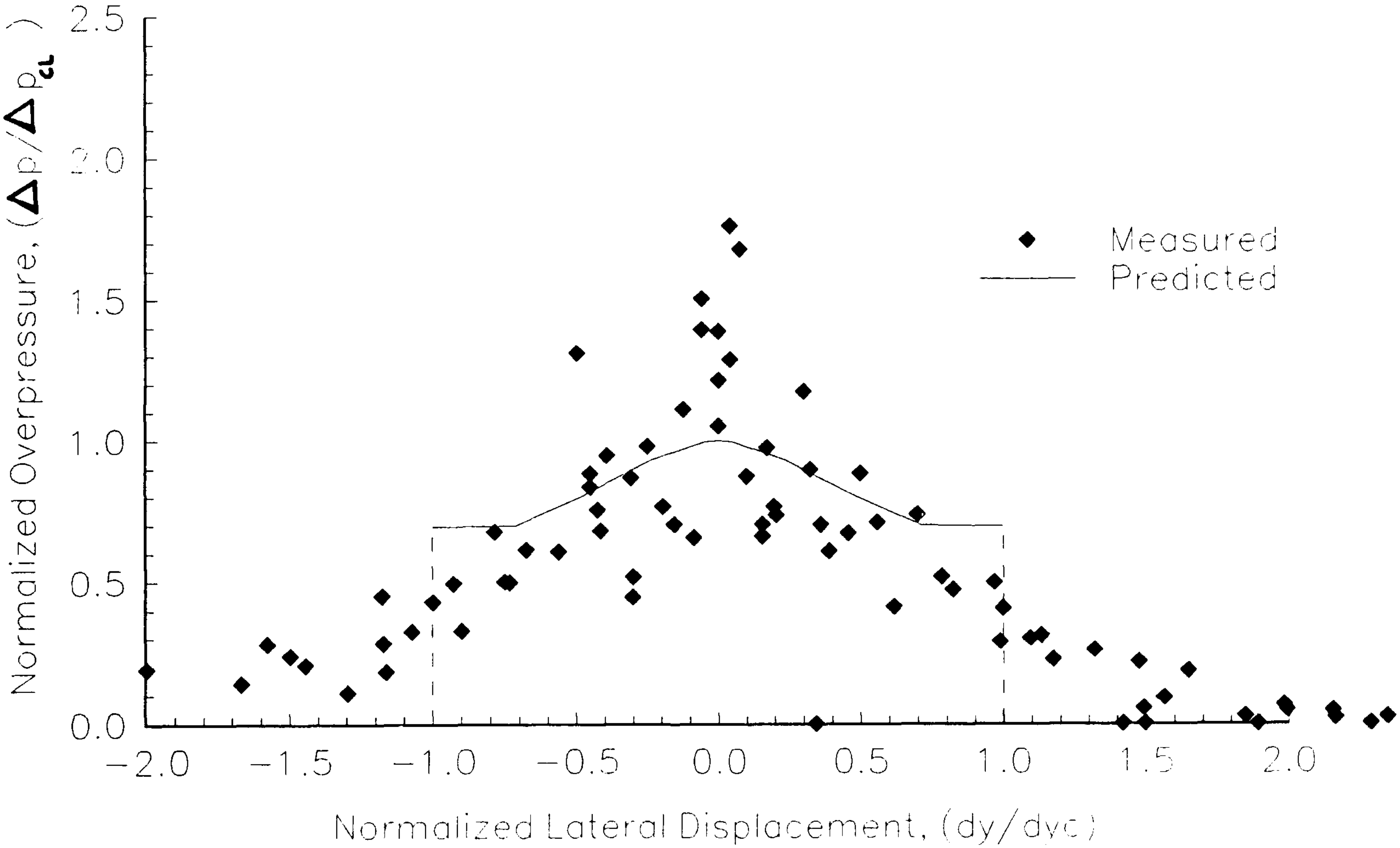

Figure 12. Normalized peak overpressures as a function of the normalized lateral propagation distance for flight with nominal conditions of 1.1 M at 14 kFt MSL

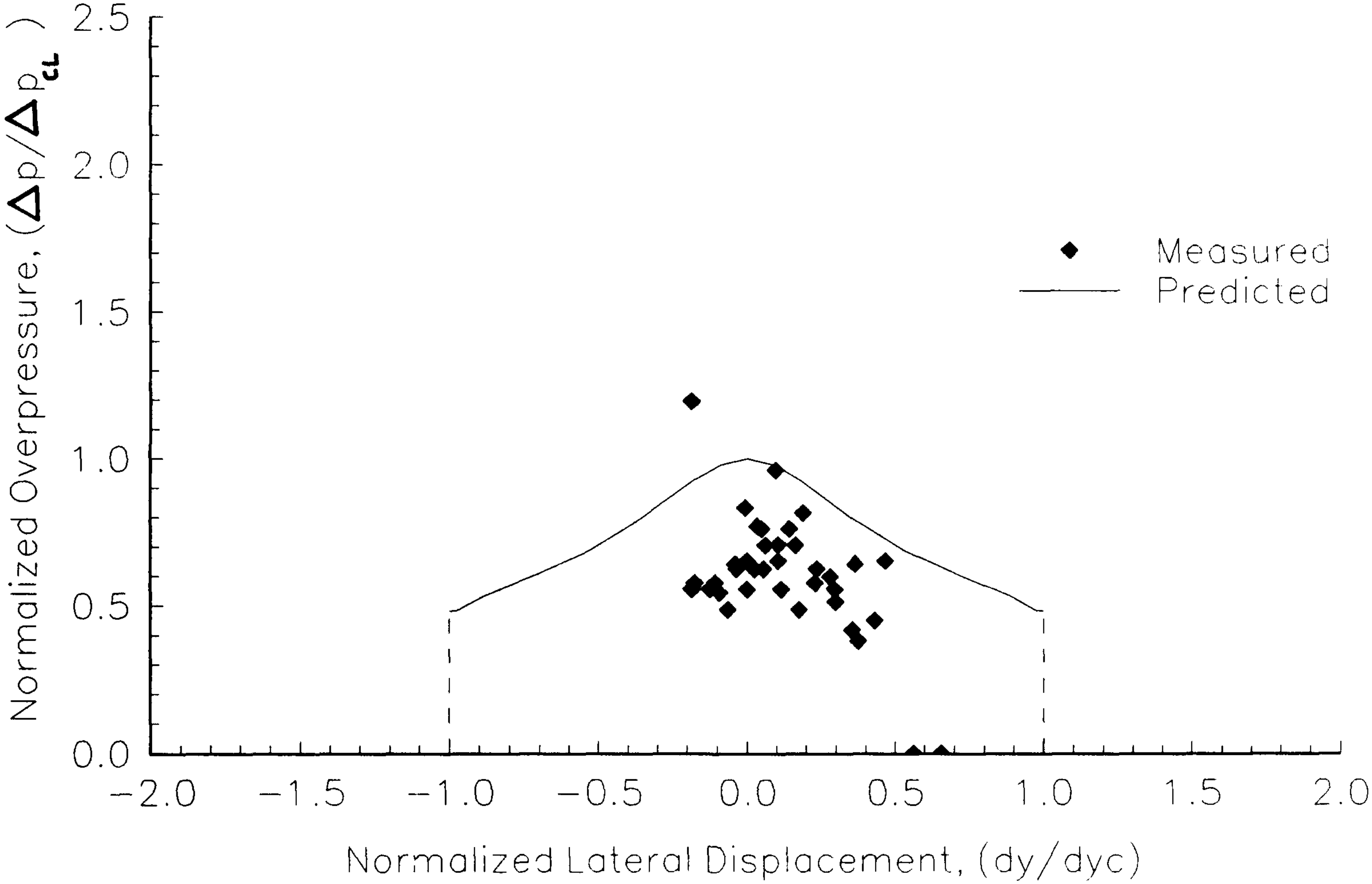

Figure 13. Normalized peak overpressures as a function of the normalized lateral propagation distance for SR-71 flights above 1.5 M

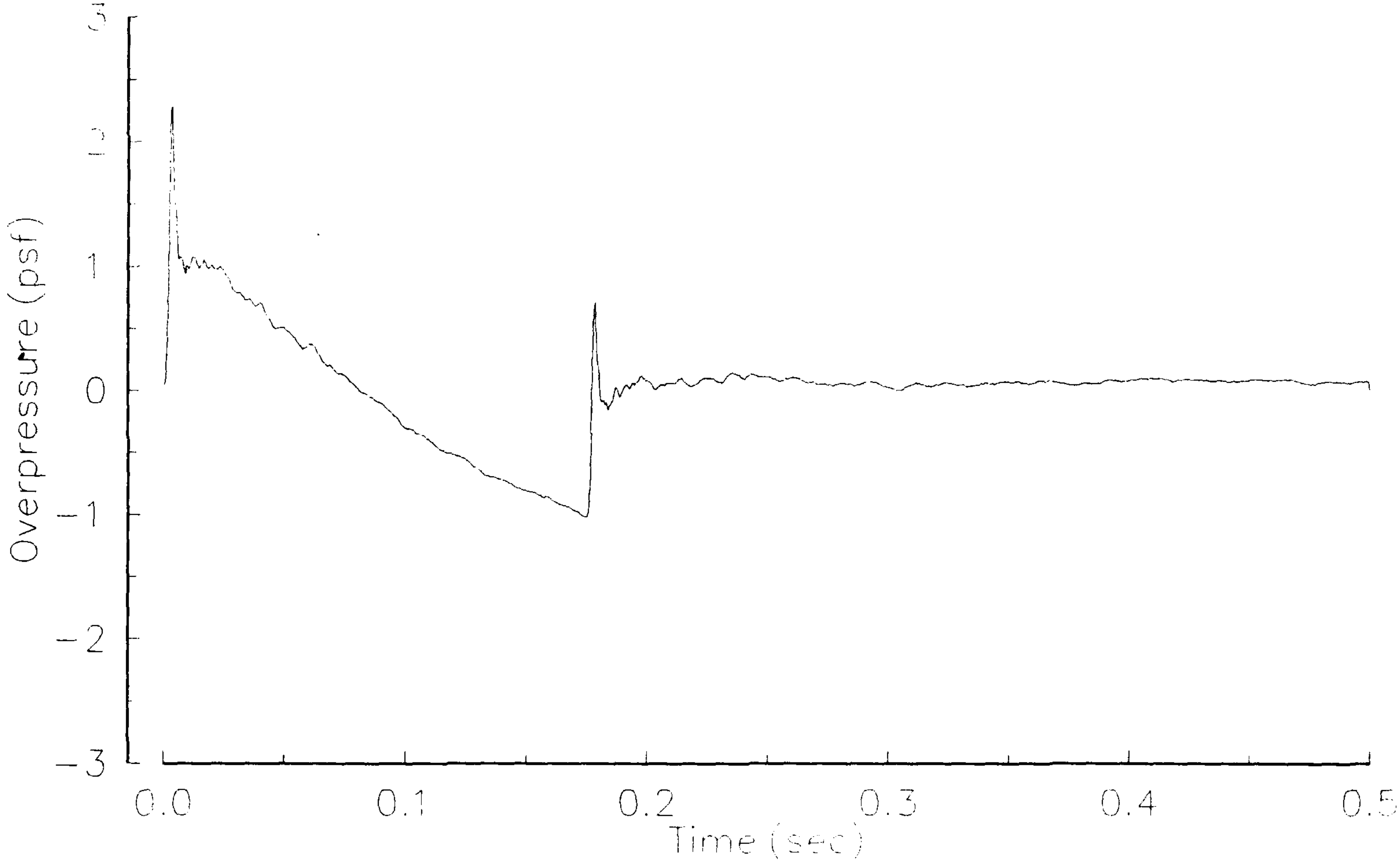

Figure 14. Peaked sonic boom signature generated by an SR-71 at 1.7 M at 52 kFt MSL (flight #32) measured 4 lateral miles from the flight track

CONCLUSION

This paper has set forth to highlight the sonic boom data obtained by Armstrong Laboratory of the USAF at Edwards AFB in 1987. The sonic boom data is contained in a digital format which can easily be analyzed on a personal computer. Information on the actual local weather conditions and the aircraft tracking are also included in this database. The BOOMFILE database can be requested from the Noise Effects Branch of Armstrong Laboratory (AL/OEBN, Area B Bldg 441, Wright-Patterson AFB, OH 45433, (513)255-3664). Basic analysis of the peak overpressure data demonstrates that they agree with previous sonic boom measurements. Also, this analysis confirms previous findings that the peak overpressure is overestimated as the lateral distance approaches the predicted lateral cutoff point. This overestimation needs to be studied further so that better estimates of peak overpressure and lateral cutoff can be obtained for sideline distances.

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